IWGGMS-21

21ST INTERNATIONAL WORKSHOP ON GREENHOUSE GAS MEASUREMENTS FROM SPACE

Overview of presentations on the use satellite measurement for facility- to urban-scale applications

Session conveners: John Worden (JPL) & Julia Marshall (DLR/Uni Leipzig)

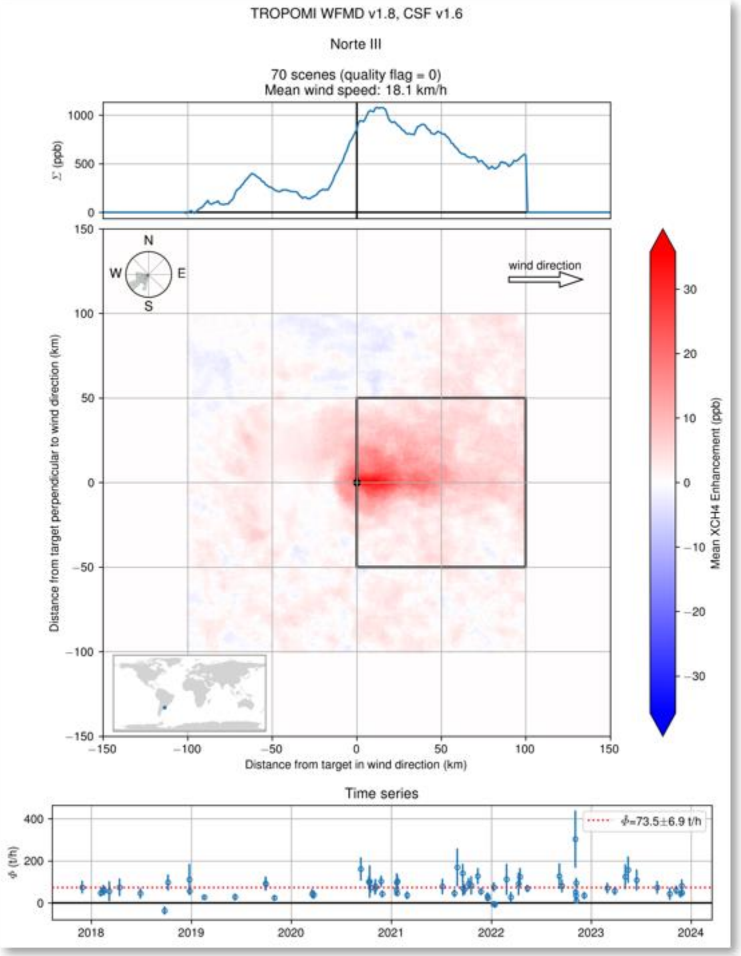
Several working on methane plume detection and emission estimation

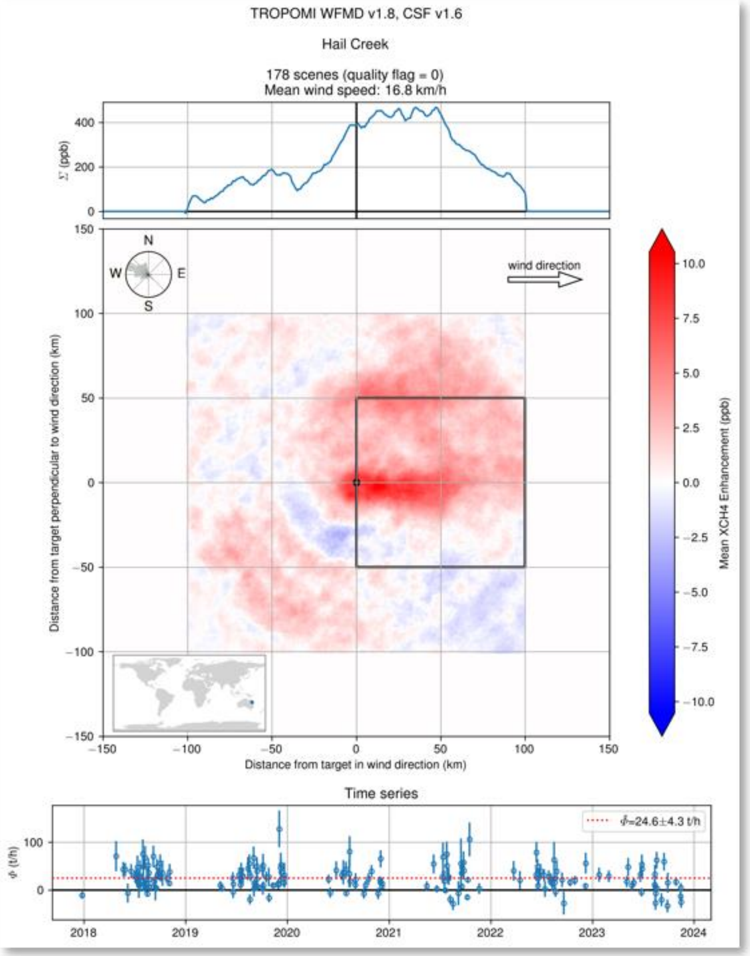
- Challenges with retrievals, especially over situations with complex albedo/terrain
- New results from MethaneSAT, also moving beyond oil and gas
- Controlled releases remain key for testing/proving capabilities
- Commercial sensors developing more data, developing statistical methods to estimate what we can potentially see with different sensors
- CO_2 plume detection and emission estimation mostly absent – a challenging problem

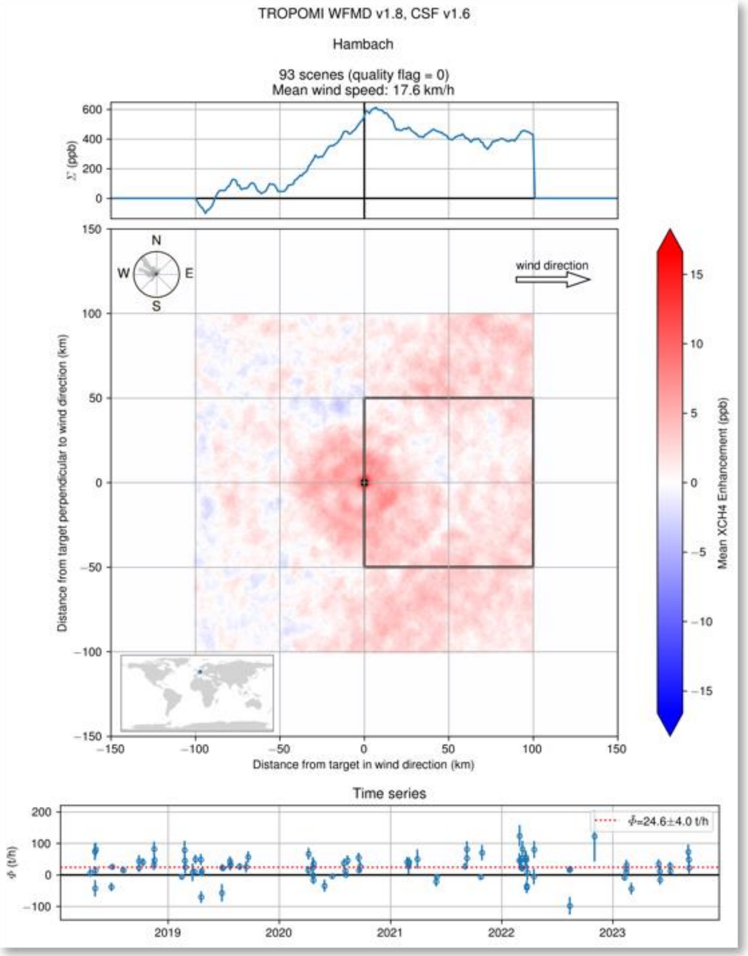
Methane: S5P/WFMD: ΔXCH4 rotat. & avg.

Michael Buchwitz
IUP Bremen

Norte III landfill Buenos Aires, Argentina	Open coal mine around Hail Creek, Australia	Open coal mine around Hambach, Germany







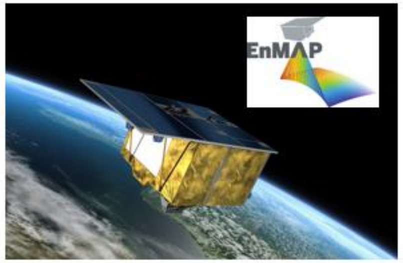
Clear average plume indicating strong isolated source

Average plume but also strong near-by sources

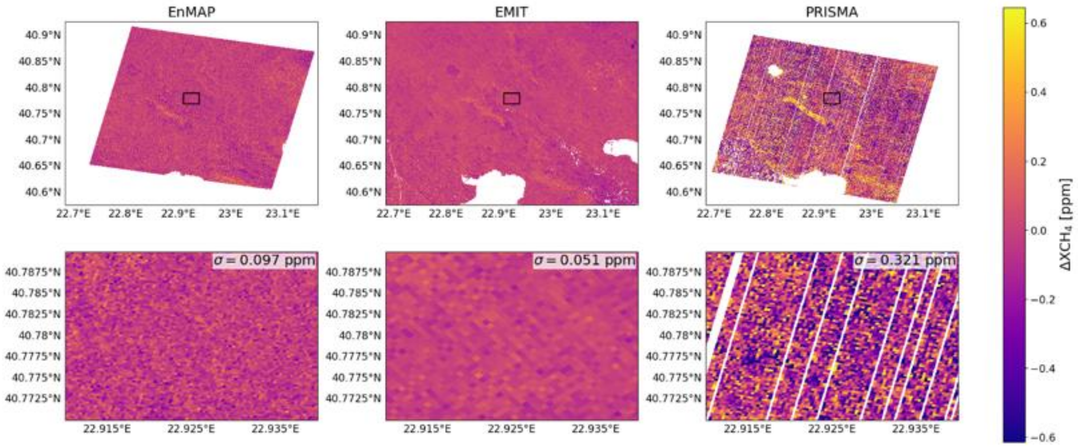
No average plume but local enhancement (challenging conditions)

(->talk Julia Marshall)

Hyperspectral Imager (HI) @ 30m/60m res.



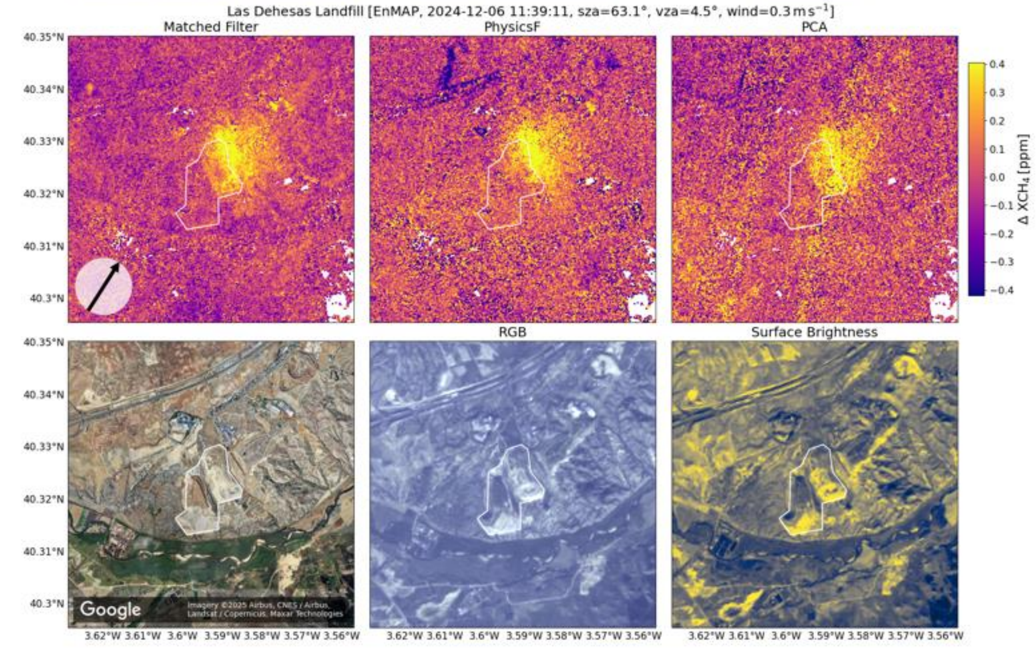
EnMAP EMIT PRISMA



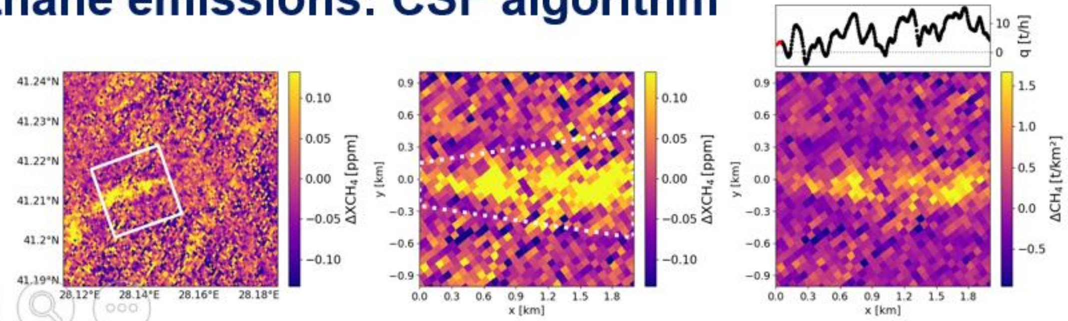
Methane enhancement retrievals:

- Three methods under development („HiFi“)
  - Differ primarily w.r.t. forward model F & measurement error covariance matrix Sε
  - **PhysicsF** (PF) (low order „DOAS polynomial“ e.g. for surface reflectivity, …)
  - Principal Components Analysis (**PCA**) (PCs instead of polynomial)
  - **Matched Filter** (MF) (e.g., no polynomial but Sε from image)

Matched Filter PhysicsF PCA



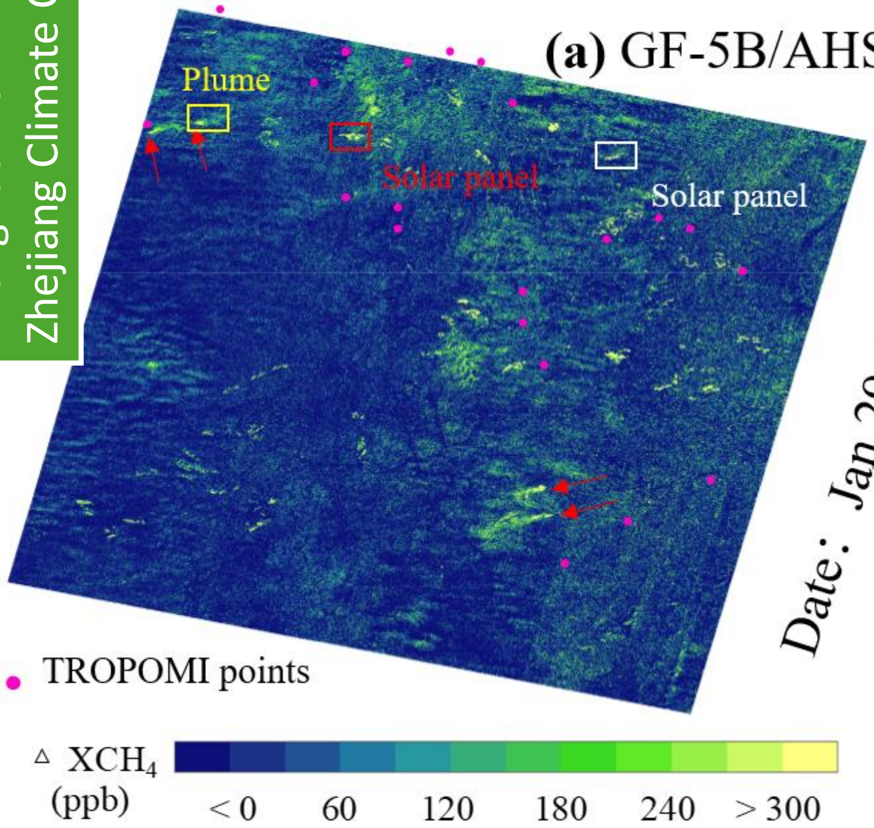
Methane emissions: CSF algorithm



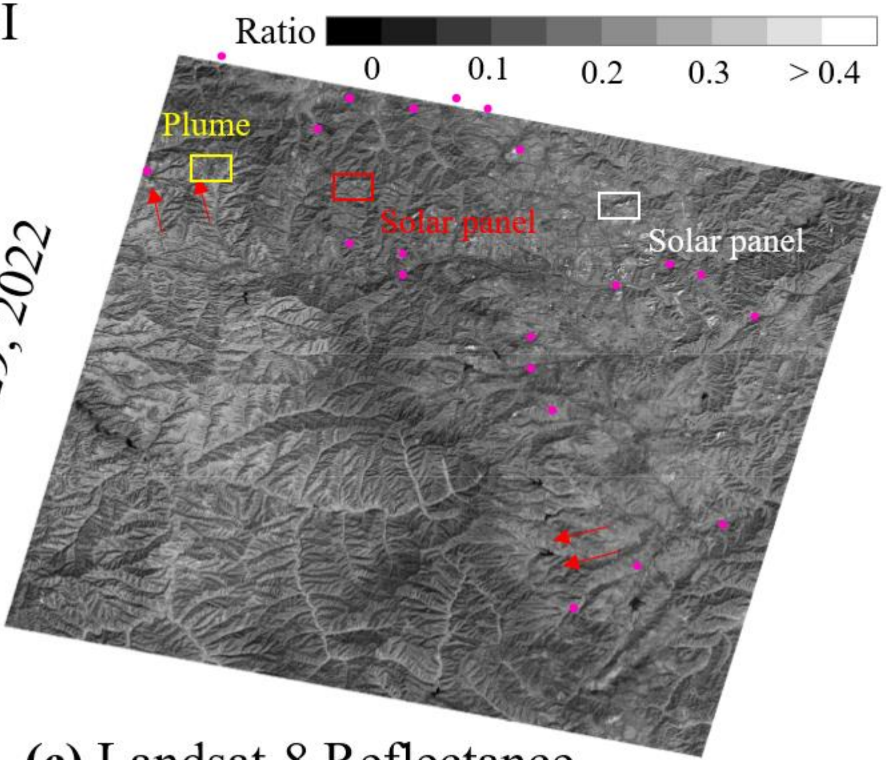
Michael Buchwitz
IUP Bremen

Zhonghua He
Zhejiang Climate Centre

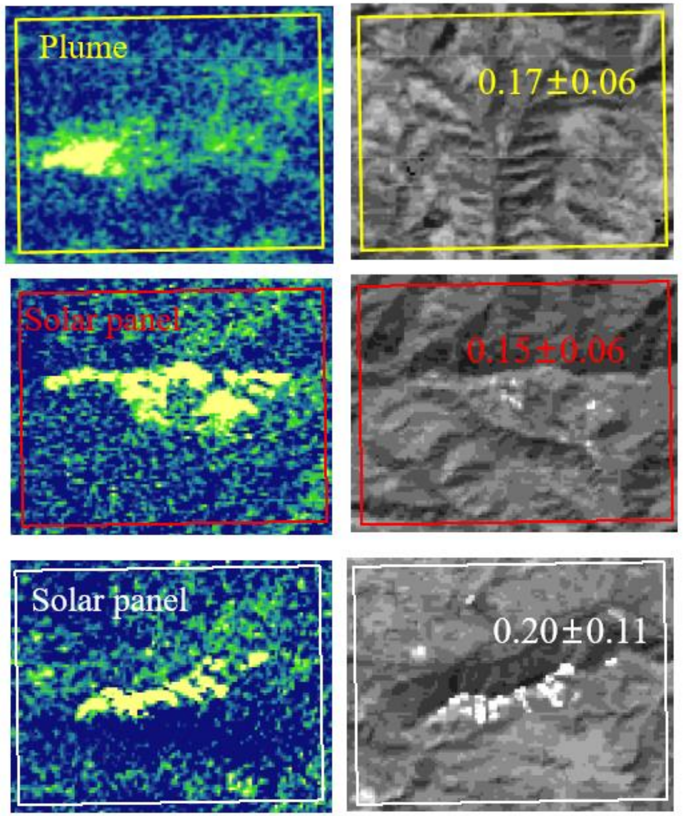
Background: Highly heterogeneous surface effect



Date: Jan 29, 2022



(c) Landsat-8 Reflectance

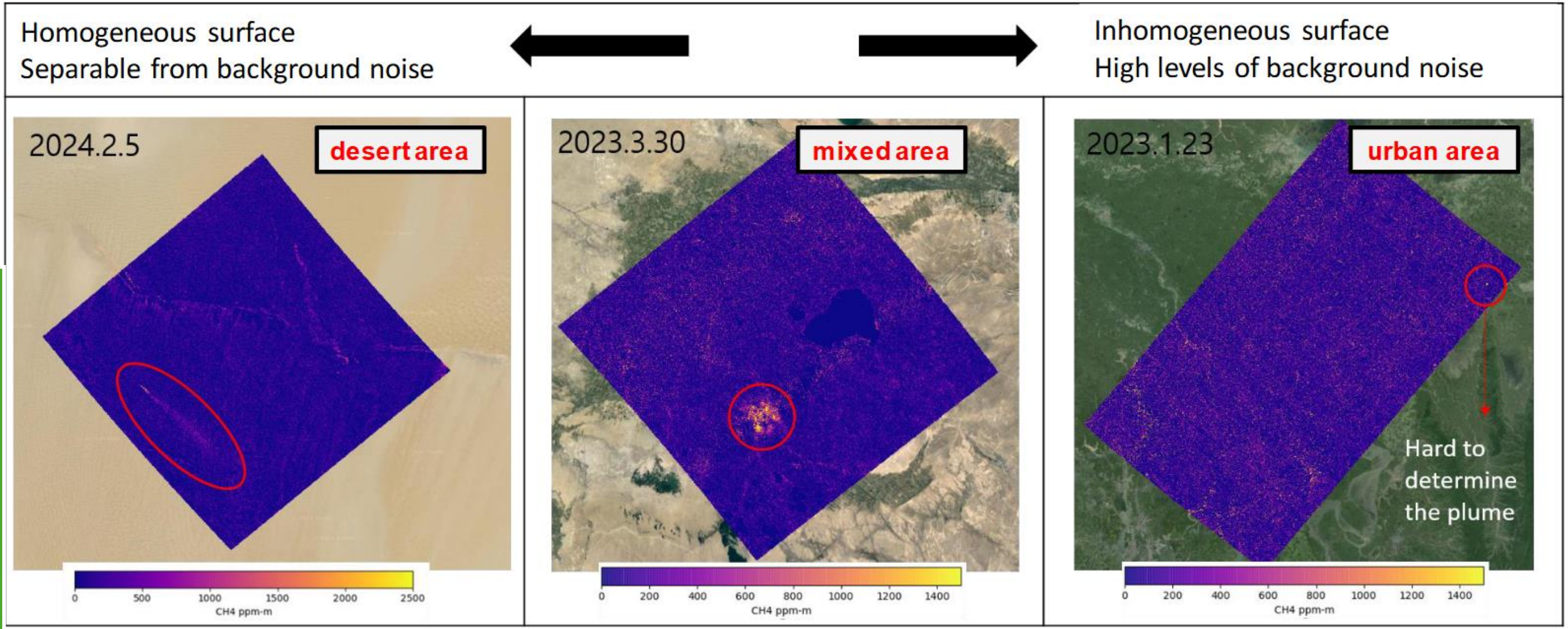


(d) Highly heterogeneous surface

(b) False positive plumes from solar panels

Evaluation and quantification ?

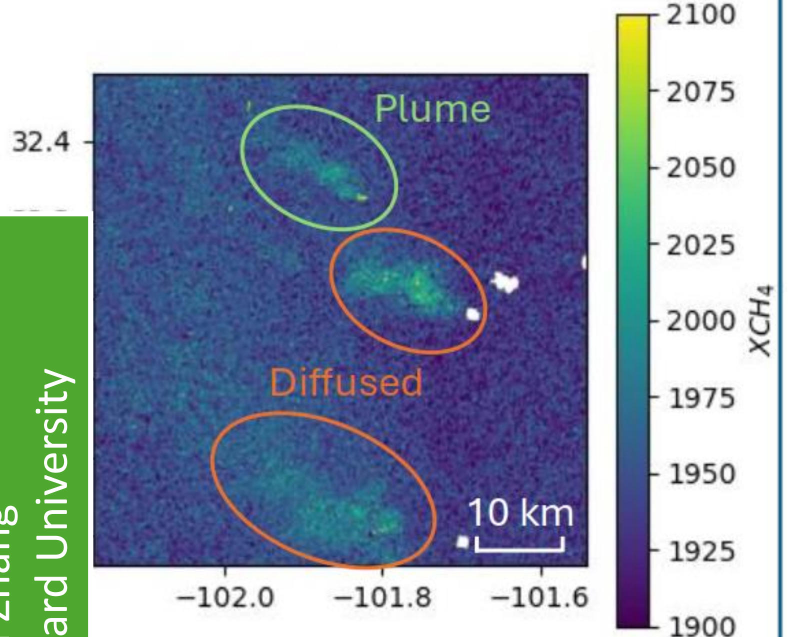
- Methane enhancement image from the EMIT instrument (Data from https://lpdaac.usgs.gov/products/emitl2bch4enhv001)
  - ✓ Methane plume (red circle) detected by the EMIT greenhouse gas algorithm
  - ✓ The ability to determine plumes is associated with the capability to separate the noisy background and methane signal
  - ✓ Plume detection ability depends on surface type: bright and spectrally homogeneous surfaces are favorable



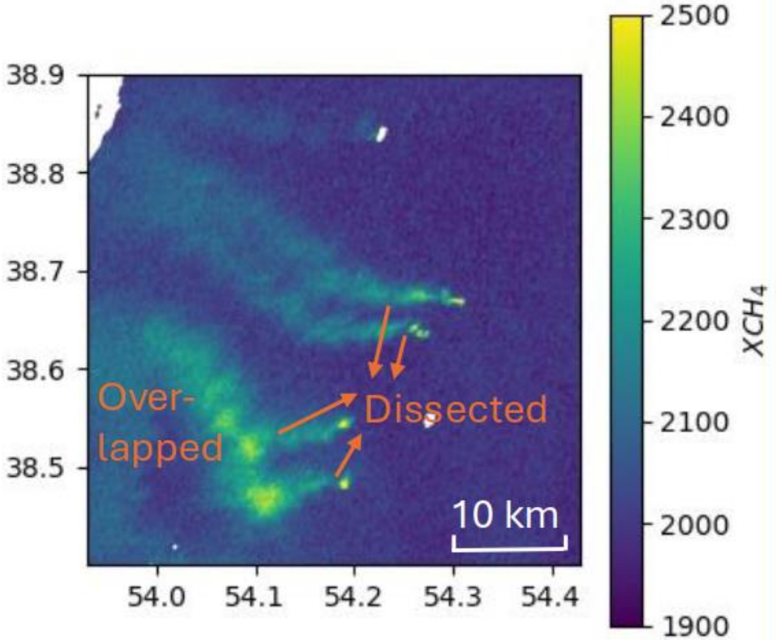
Yu-Ri Lee
Seoul National University

Unique Challenges

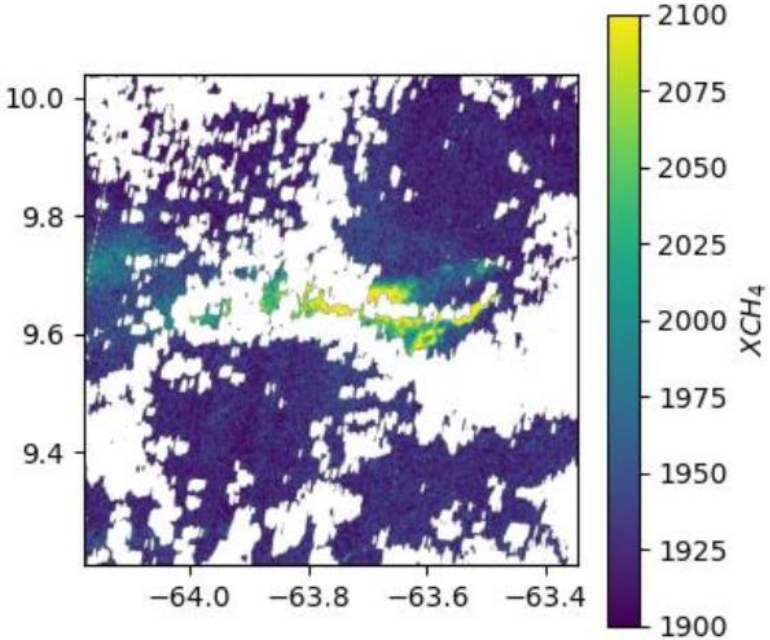
MethaneSAT's high sensitivity enables observations of diffused emissions, whose lower enhancements make it harder to attribute them to certain source infrastructure.



MethaneSAT's large spatial coverage provides traces of long plume tails, increasing the probability of dissected or overlapped plume masks.

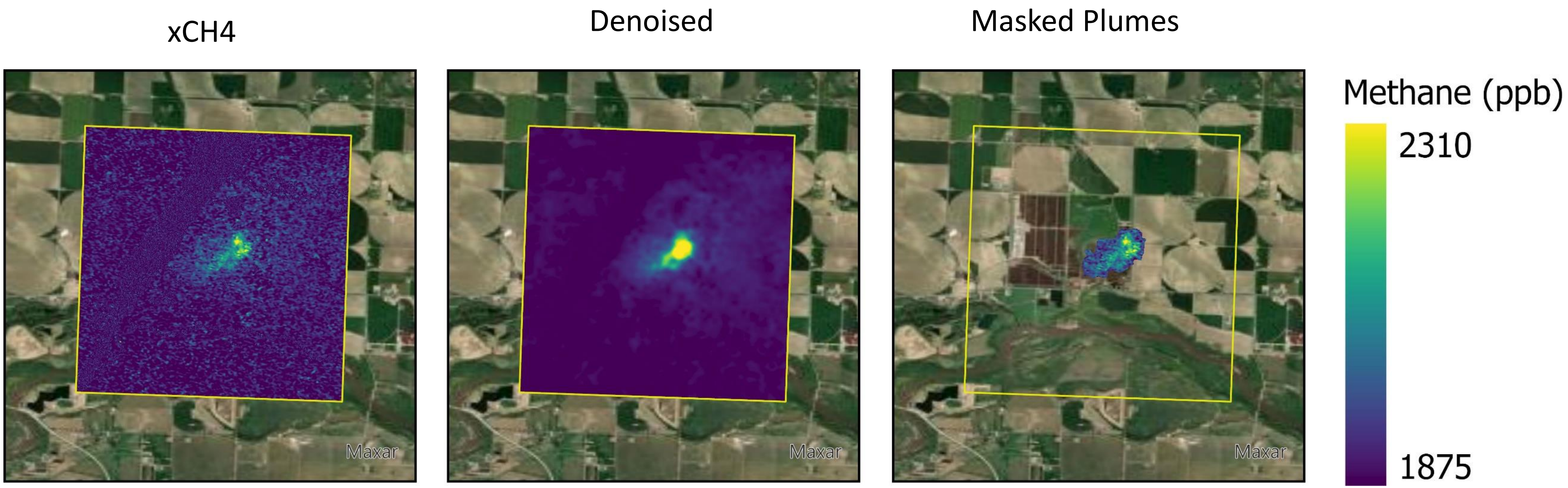


Cloud screening corrupts plume shape, increasing the difficulty of source localization and quantification.



Zhan Zhang
Harvard University

Example data: Diamond Feeders in Colorado



<u>Plume (kg/hr)</u>
Estimated*: 355
above plume: 846
Measured range: 171-1020

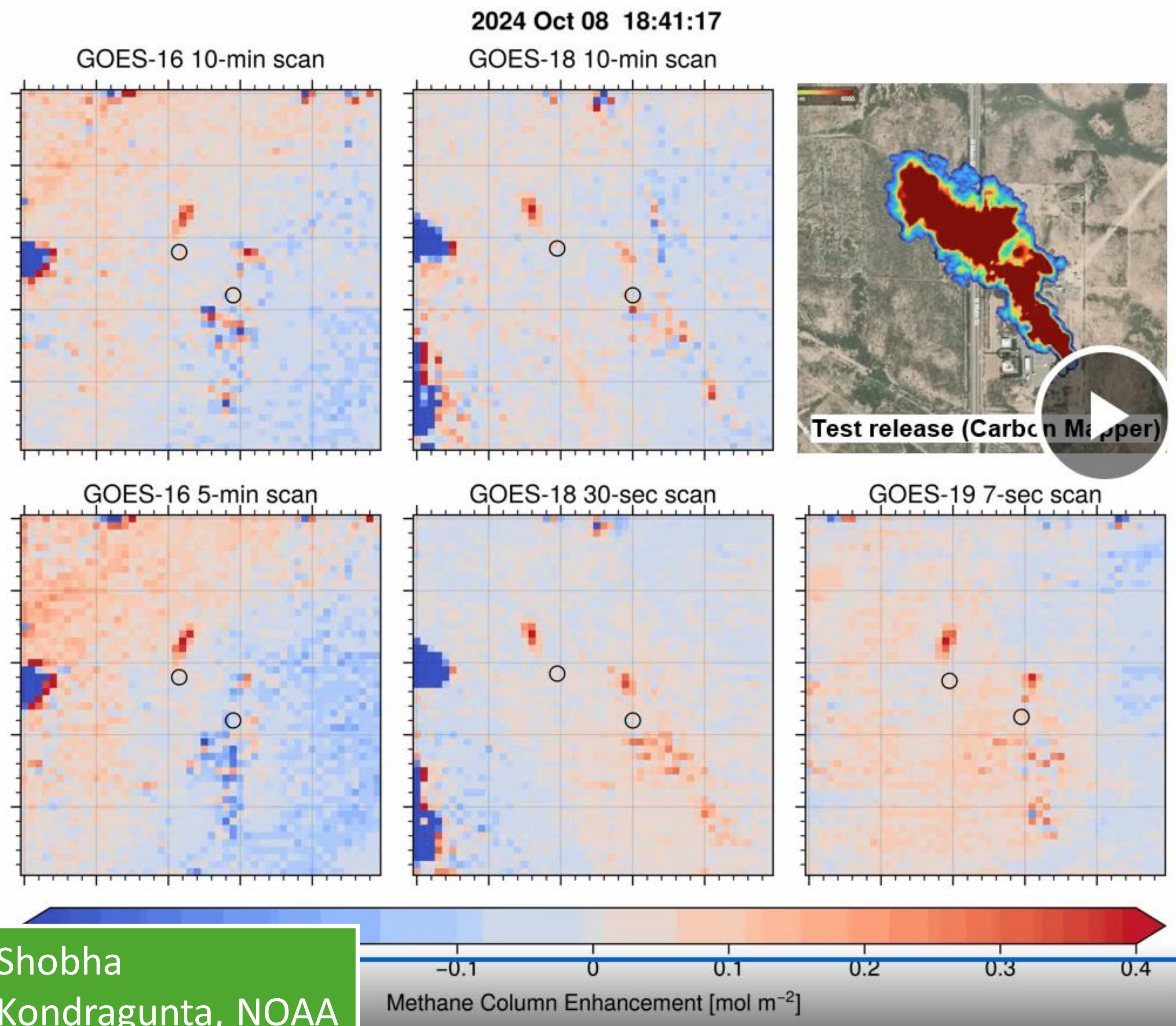
<u>Per animal (g/hr)</u>
EPA estimate for beef: 18
Above plume*: 42

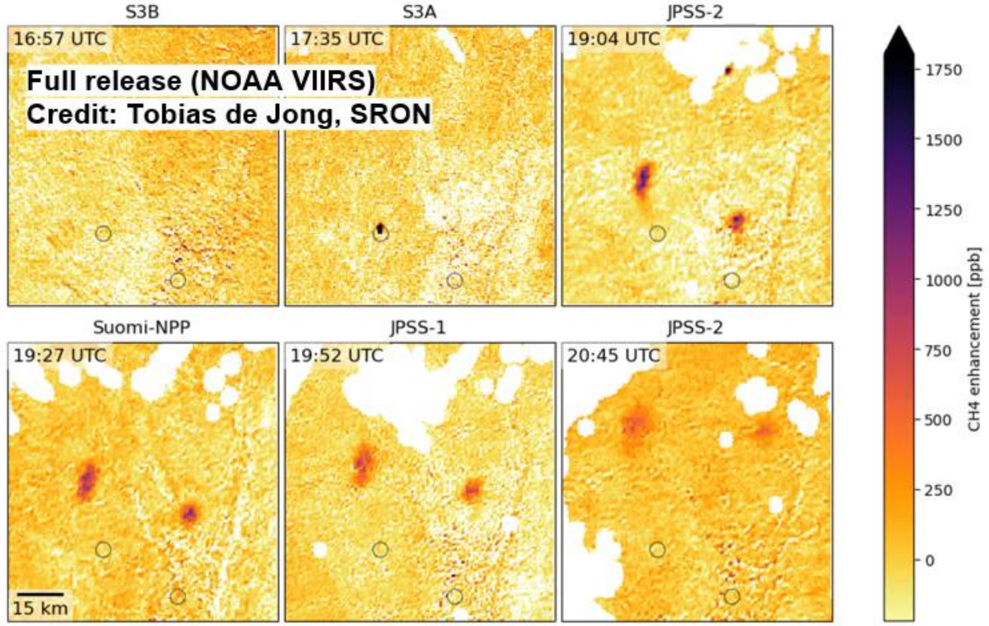
*Based on the maximum capacity of registered and permitted feedlots from Colorado State

Sara Mikaloff-Fletcher
NIWA

NOAA's Very Large Methane Release (VLMR) Experiment: October 2024

Coordinated measurements of a planned pipeline maintenance event by NOAA NESDIS, ARL, CSL, GML & Carbon Mapper





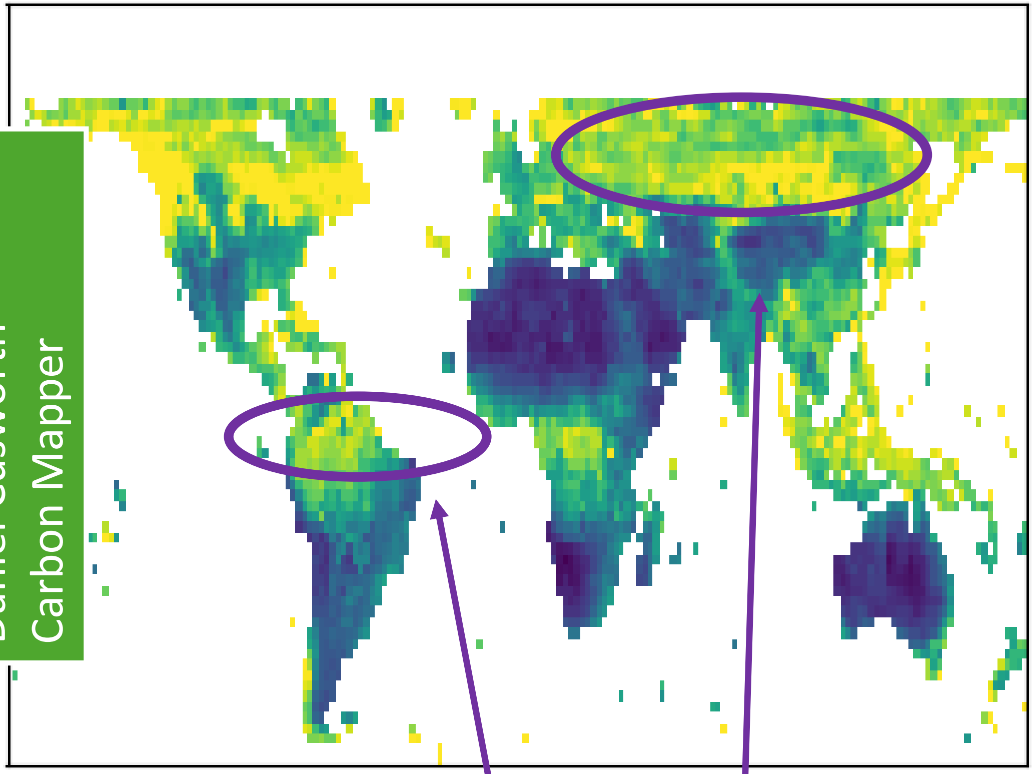
Shobha Kondragunta, NOAA

Team acknowledges Pipeline Research Council International and their members for support with this experiment

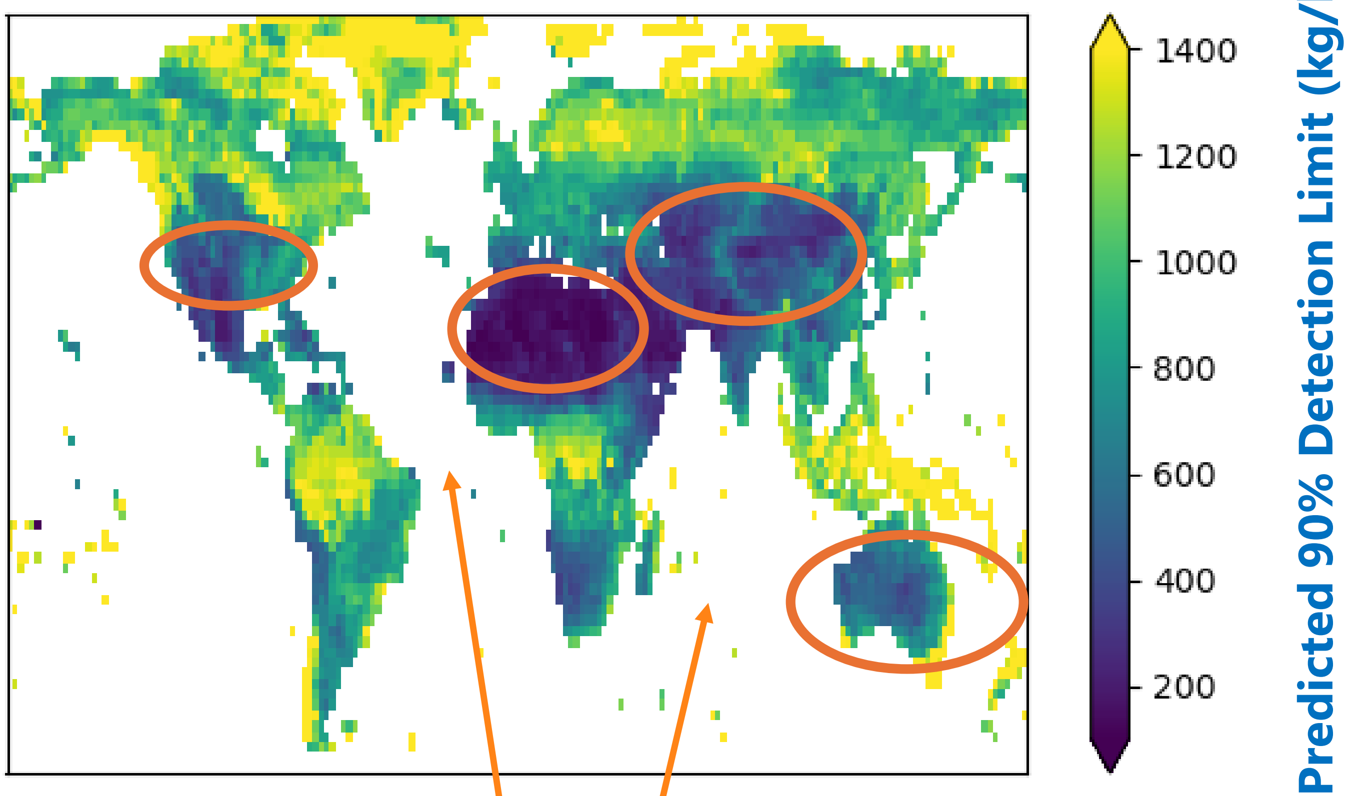
Estimate of 90% probabilistic detection for Tanager (1x8 mode)

Daniel Cusworth
Carbon Mapper

January 90% POD Prediction



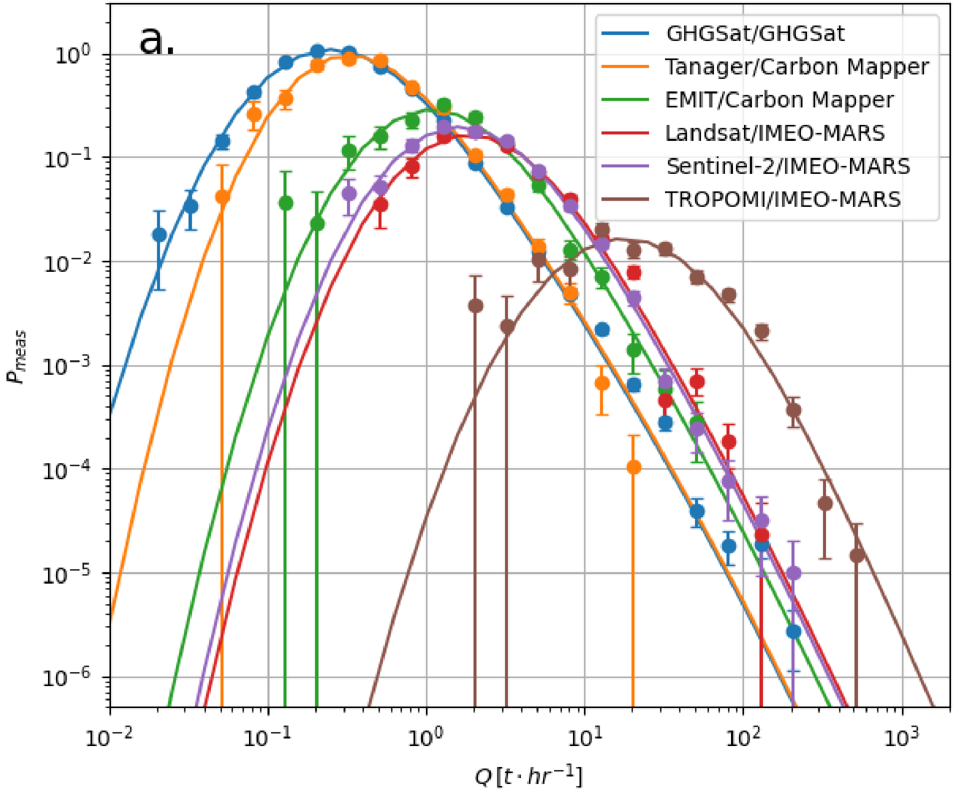
June 90% POD Prediction



Even in challenging regions (sub-artic, tropic), expect reliable detection to class of super-emitters

Anticipate reliable detection to most/all super-emitters across multiple oil&gas basins globally throughout year in **lowest sensitivity** mode

CONTROLLED RELEASES VS "IN THE WILD"



- Analysis presented by Dylan Jervis
- Suggests higher detection limits "in the wild" vs. controlled releases
- Applies to our satellites and others
- *Controlled releases don't tell the whole story but we can push to close the gap – possibly with AI*

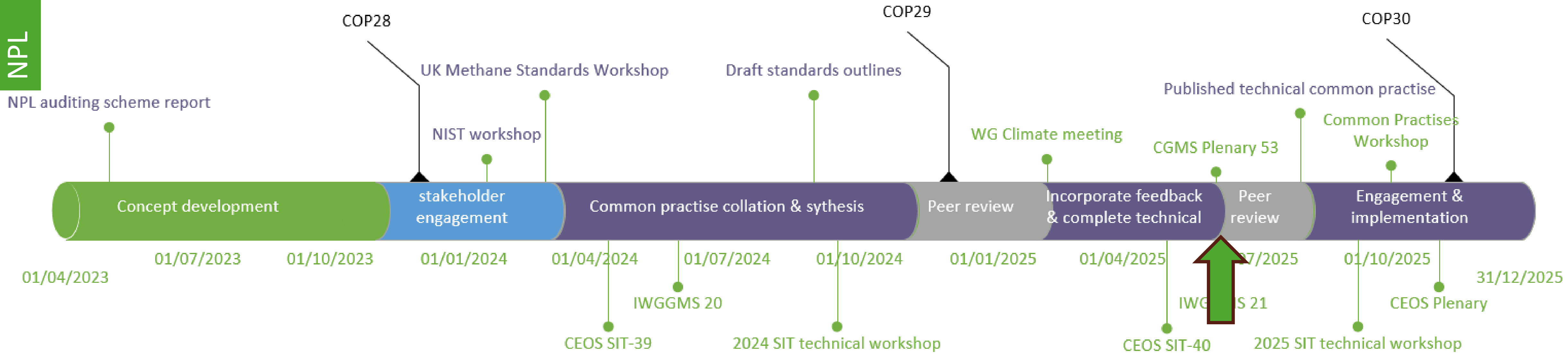
Jason McKeever
GHGSat

Community Practices & Methodology

•**Green**: Overview of the current status of **community-accepted practices** for methane plume detection, emission quantification, and validation.

- 2024 – outline development & peer review
- 2025 – detailed completion, peer review & v1 finalization for end 2025
  - now v0.4 out for community final review
  - Final community review in June 2025 leading to static v1.0 July 2025.
  - Case study development over Summer 2025.
  - Common practices workshop late 2025

Paul Green
NPL



Some work on the city scale

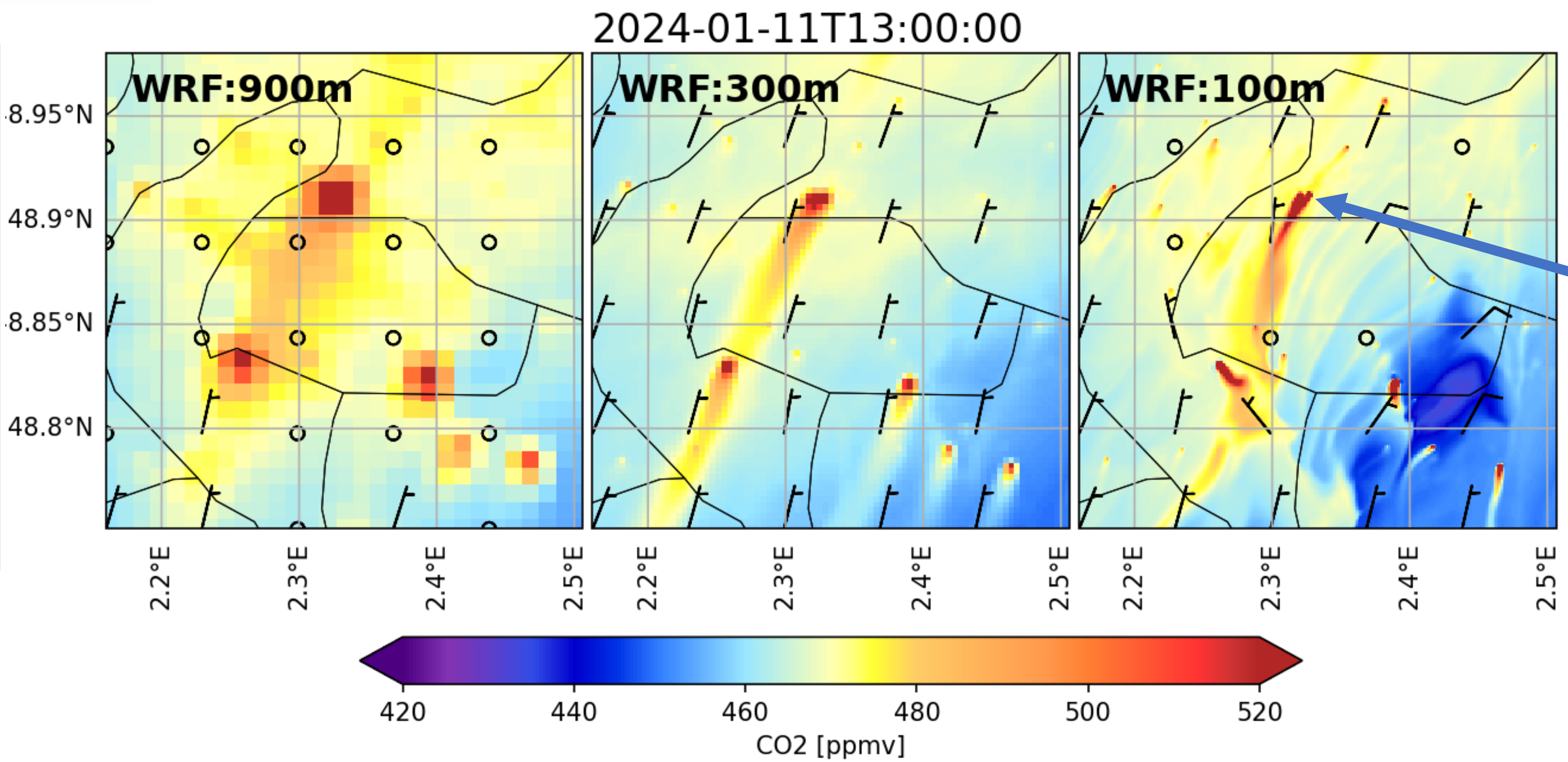
- Both satellite- and ground-based measurements considered
- Modelling at this scale presents different challenges
- Emission ratios between different tracers provides additional information

Funded by the European Union

CATRINE
Carbon Atmospheric Tracer Research to Improve Numerics and Evaluation

WRF CO2 for 2024-01-11 at 13UTC at 10m above the surface

Alohotsy Rafalimanana
Université de Reims



- At 100 m resolution, **two distinct point sources** are clearly resolved, whereas they appear merged into one at 900 m
- Finer resolutions better capture localized features that are smoothed out at coarser scales.

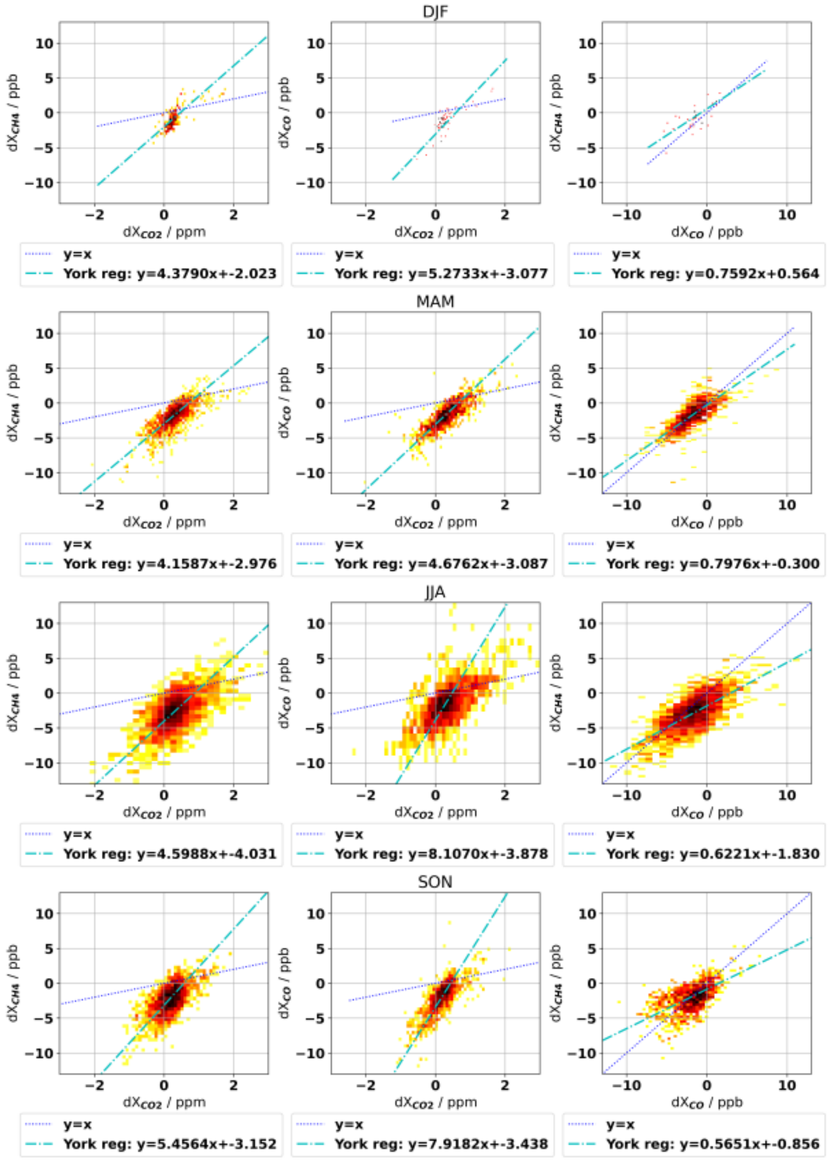
- In the **low-resolution domains**: the plume appears larger and less concentrated
- In the **high-resolution domain**: the plume appears smaller, more concentrated, and better defined.
- **Local wind patterns** influence the dispersion of CO_2, resulting in differences across the various resolutions.

Starting an enhancement ratio analysis for Toronto

- Gradient enhancements ratios are calculated by using Eq. 1 and calculating the ratio of dX_{CH4}:dX_{CO2}, dX_{CO}:dX_{CO2}, or dX_{CH4}:dX_{CO} as the slope of the linear regression.

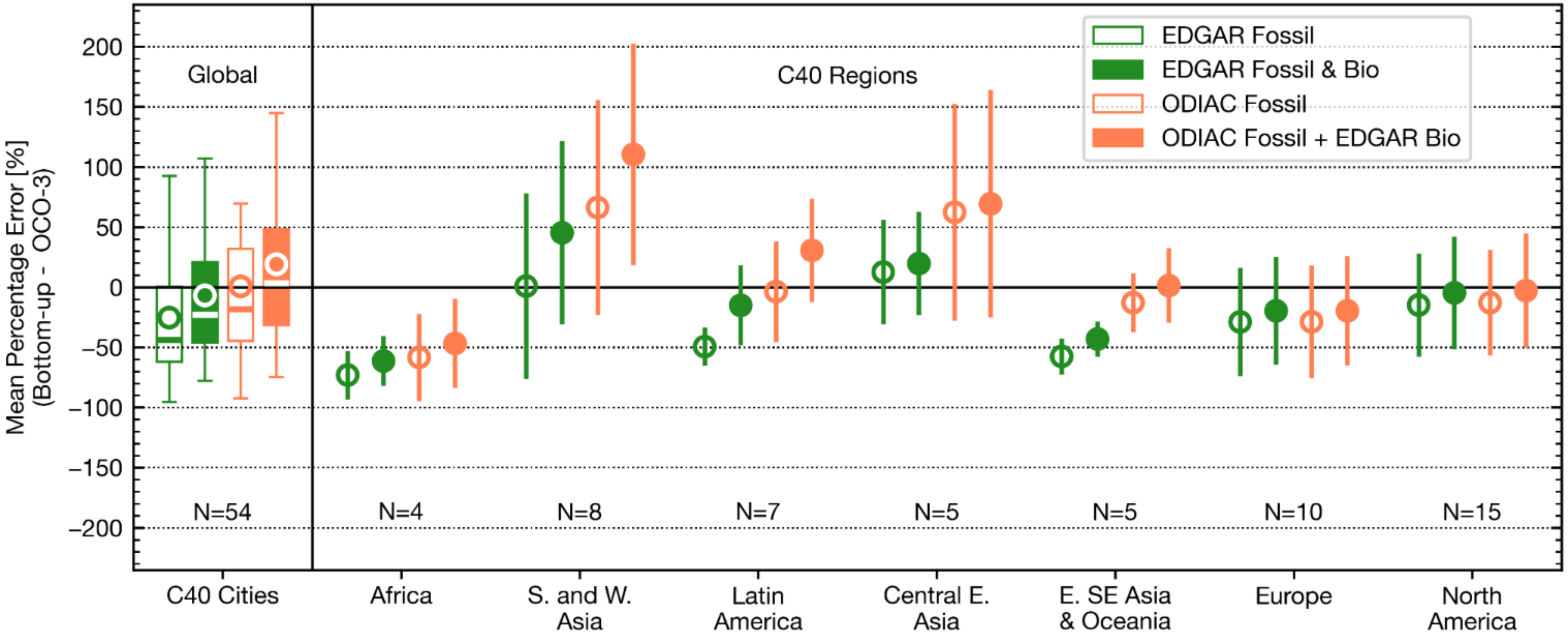
$$dXgas[site] = \frac{Xgas[site] - Xgas[reference]}{ak_{gas}^{surface}} \quad (1)$$

- We can multiply the enhancement ratio by inventory estimates of CO_2 or CO emissions, respectively, to obtain a range of CH_4 and CO emission estimates for a suite of models.



Nicole Jacobs
University of Toronto

Regional comparison of Bottom-up and Satellite-based Emission Estimates



- Cities in N. America showed the best agreement between bottom-up and satellite-based estimates, with MPE ranging from −15 ± 41% for EDGAR fossil to −3 ± 46% for ODIAC total emissions.
- For cities in Africa, both EDGAR and ODIAC significantly underestimated emissions compared to satellite-based estimates. Africa is the only region where satellite-based estimates fall outside the 1 sigma range of all four bottom-up emission estimates.

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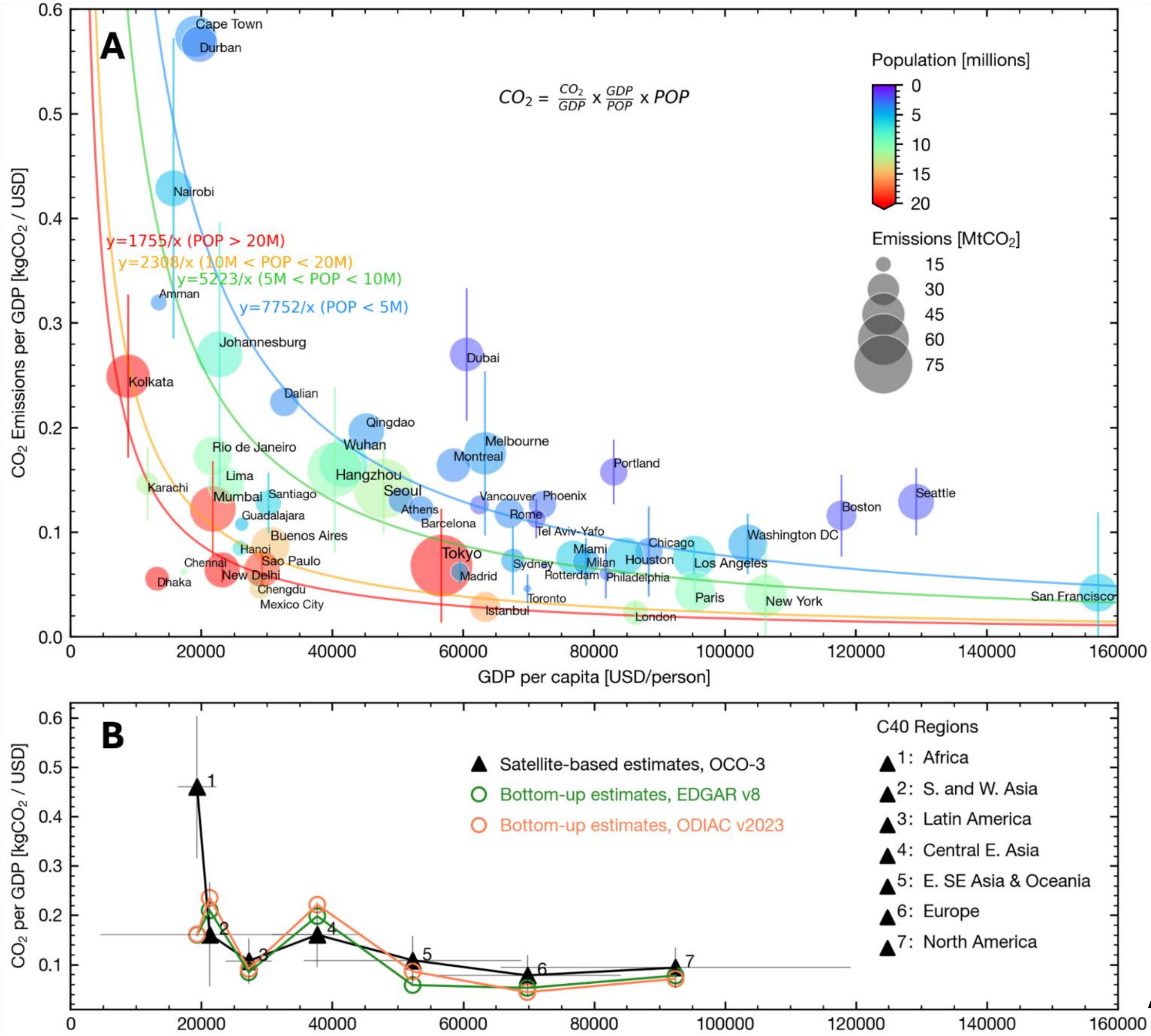
Ahn et al. (In review)

Doyeon Ahn
Goddard

Satellite-based Kaya Identity Analysis of Global Cities' CO_2 Emissions



Ahn et al. (In review)

- We applied a modified Kaya Identity to decompose our satellite-based emission estimates for the 54 C40 cities: $CO_2 = CO_2/GDP \times GDP/Population \times Population$
- High-income cities tend to have less carbon-intensive economies: North American cities emit 0.1 ± 0.04 kg CO_2 per USD of economic output , while African cities emit 0.5 ± 0.14 kg CO_2 per USD
- A similar inverse relationship —the decoupling of CO_2 emissions from economic growth— is observed when cities are grouped into global regions.
- Per capita emissions decrease with increasing population size, from 7.7 tCO_2/person for cities under 5M residents to 1.8 tCO_2/person for cities over 20M residents.

Doyeon Ahn
Goddard

Questions/needs that emerged from the session

1) What else is needed to monitor urban emission? Will CO2M solve this problem or do we need tailored observation? Or a combination of satellite and ground-based remote-sensing/in-situ measurements?

2) How can we coordinate methane release validation experiments so that the constellation of satellites can all take advantage of these efforts?

3) Most plume-scale measurements are after fossil plus concentrated cattle and waste. Do we have the capability to quantify concentrated livestock facilities?

4) What else is needed to characterize the true probability of detection (POD) of different instruments?

5) What are general thoughts on using plume-class observations to quantify urban emissions where albedo is high/heterogeneous?